



Heriot-Watt University
Research Gateway

Management and environmental risk study of the physicochemical parameters of ballast water

Citation for published version:

Ghods, NN, Ghadiri, M & Fruh, W-G 2017, 'Management and environmental risk study of the physicochemical parameters of ballast water', *Marine Pollution Bulletin*, vol. 114, no. 1, pp. 428–438.
<https://doi.org/10.1016/j.marpolbul.2016.09.062>

Digital Object Identifier (DOI):

[10.1016/j.marpolbul.2016.09.062](https://doi.org/10.1016/j.marpolbul.2016.09.062)

Link:

[Link to publication record in Heriot-Watt Research Portal](#)

Document Version:

Peer reviewed version

Published In:

Marine Pollution Bulletin

General rights

Copyright for the publications made accessible via Heriot-Watt Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

Heriot-Watt University has made every reasonable effort to ensure that the content in Heriot-Watt Research Portal complies with UK legislation. If you believe that the public display of this file breaches copyright please contact open.access@hw.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Management and environmental risk study on the physicochemical parameter of ballast water

Nosaibeh Nosrati-Ghods¹, Mehdi Ghadiri^{2*}, Wolf-Gerrit Früh¹

¹School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, United
Kingdom

²Young Researchers and Elite Club, South Tehran Branch, Islamic Azad University, Tehran, Iran

*Corresponding author: M_ghadiri10@yahoo.com

Abstract

Shipping is a vital industry for the global economy. Ships' stability, provided by ballast water, is a crucial factor for cargo loading and unloading processes. Ballast water treatment has practical significance according to environmental issues, ecosystem, and the health of human beings, since ships should discharge this water into environment before loading their cargos. This work brings together the common methods for ballast water management – exchange, heating, filtration, ultrasonic, ultraviolet, chemicals, and gas super saturation – to select the best method among common methods. This study compares water temperature, salinity, dissolved oxygen, polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Co, Cr, Ni, Pb) for ballast tanks of selected ships versus the recipient port environment in the Persian Gulf as a case study. Whether it is more appropriate to exchange ballast water in the ocean and/or treat it on board to prevent inadvertent effects on the environment's physicochemical condition, is related to vessel characteristics, legislation and the environmental condition. Ecological risk study showed that amounts of PAHs and salts in ballast water are close to that of seawater, but the value of Cr (2.1 mg/litre) and Ni (0.029 mg/litre) in ballast water is higher than seawater (1 and 0.004 mg/litre, respectively).

Keywords: Ballast Water, Management, Ecological Risk Study, Physiochemical condition

1- Introduction

Shipping is a vital industry for the global economy. Ships' stability is an important factor during the cargo loading and unloading processes. Stability of ships at sea can be maintained by ballast water. Ships carry approximately 10 to 12 billion tons of ballast water across the oceans every year in which thousands of aquatic species, as well as heavy metals, are being transferred (Tootsie, 2002). Ballast water treatments have practical significance for environmental and health concerns for human beings, since ships take in ballast water containing different physicochemical parameters - temperature, salinity, dissolved oxygen (DO), polycyclic aromatic hydrocarbons, heavy metals (Co, Cr, Ni, Pb) -, transfer them in transport and discharge this water before loading their cargos.

It is impossible to neglect the harmful consequences of physicochemical parameters of ballast water as in the case of heavy metal which has negative effects on aquatic organisms suppressing growth in marine life (Govind and Madhuri, 2014). Chinese and Russian industrial pollution such as heavy metals in the Amur River have devastated fish stocks (Sharma, 2009). While being toxic to marine life, polycyclic aromatic hydrocarbons (PAHs), are very difficult to clean up, and last for years in the sediment and marine environment (Panetta, 2003).

After identifying the adverse effect of transferring ballast water by ships across the world in 2004, the International Maritime Organization (IMO) accepted the International Convention on ballast water management for a safe and healthy environment (David and Gollasch, 2008). The Convention was set to come into force 12 months after being ratified by 30 states that cover 35 percent of the world merchant shipping tonnage. As of August 2, 2016, the convention has been ratified by 51 nations but their contribution to the world merchant shipping tonnage is only 34.87%. Hence, it has not come into force so far (International Maritime Organization, 2016).

As the Persian Gulf has shallow water, it has a high marine biodiversity and high temperature (Ngoka, 2015). The region of the Gulf is almost 241,000 square kilometer, surrounded by Iran,

Qatar, Bahrain, Saudi Arabia, Oman, United Arab Emirates (UAE), Kuwait and Iraq. The marine life in this Gulf includes sea turtles, marine birds, dugongs, whales, dolphins and over 500 fish species (Hellyer and Aspinall, 2005). Many of these species are native and highly dependent on the ecosystem of the Gulf (UNEP, 1999).

Several studies considered possible solutions to mitigate effects of ballast water on seawater (Bai et al., 2005; Balasubramanian et al., 2008; Bax et al., 2003; Costello et al., 2007; David and Gollasch, 2015; Delacroix et al., 2013; Dunstan and Bax, 2008; Firestone and Corbett, 2006; Gavand et al., 2007; Gonçalves and Gagnon, 2012; Liltved et al., 2011; Nanayakkara et al., 2011; Romero-martínez et al., 2014; Stehouwer et al., 2015; Tsolaki and Diamadopoulos, 2010; Werschkun et al., 2014; Williams and Grosholz, 2008; Zhang et al., 2005), but few of them considered effects of ballast water management on the physiochemical factors of water discharged into the port environment.

This study investigated the effect of common ballast water management on seawater by assessing the effects of chemical, physical, mechanical treatments and exchange on the physiochemical factors of the ballast water discharged into the port environment and select the best of them. The choice of parameters to be investigated was determined by those known to affect ballast water management, namely water temperature, salinity, dissolved oxygen, PAHs and heavy metals in ballast water discharged into the port versus the recipient port environment.

Before introducing our study in Section 3, common methods for ballast water management methods are described in the following section.

2- Ballast water management

Observing appropriate ballast water management is necessary to avoid problem through the invasion of species carried by ballast water. The methods of ballast water handling are ballast water

exchange based on D-1 standard and ballast water treatment based on D-2 standard (Germanischer Lloyd SE, 2013). The D-1 standard for water exchange specifies that 95% of ballast water should be exchanged or, when pumping is being used, that every tank has been pumped three times. The D-2 Standard for ballast water treatment is based on maximum concentration of specified organisms (Gollasch, 2006).

2-1- Ballast Water Exchange (BWE)

Ballast water exchange is the most practical and prevalent method because the translocation of species cannot happen through this method (David and Gollasch, 2008). The three methods of exchanging ballast water are: i) to discharge the tanks and subsequently refill, ii) to discharge and refill simultaneously, and iii) to release water through the bottom of ships and simultaneously pump water into the tank that is known as the Dilution method (Gollasch, 2004). Despite the fact that BWE would be the most cost-effective and time-saving, it is impossible to ignore the following risks to the vessel and crew with regard to ballast water exchanges: loss of stability; over stress; sloshing loads; torsional loads; reduction in maneuverability; reduction in draughts; Icing; occupational hazards and fatigue of crew; excessive forces on securing arrangements of containers or special cargo.

2-2- Ballast Water Treatments (BWTs)

Ballast water treatment is divided into three major categories (Airahuobhor, 2010), mechanical, physical and chemical treatments. A single method usually cannot meet the requirements of the International Maritime Organization in a way that is safe, effective and economic (Wu et al., 2011). Thus, a combining of two or more treatment systems of ballast water is usually more practical and efficient. Some of these are introduced in more detail in the following section.

2-2-1- Mechanical and physical treatment:

Of mechanical treatments, filtration is effective in removing cloudy particles, viruses, bacteria and parasites (Nasser et al., 2002; Tang et al., 2009) or hydrocyclone technology (Lloyd's Register Group, 2010). Exposing microorganisms to ultraviolet radiation is a practical and effective way to inactivate microorganisms (Tang et al., 2009). However, when particles are suspended, the effectiveness of ultraviolet is diminished through the attenuation of the radiation. For that reason, a combination of filtration and ultraviolet can be used (Perakis and Yang, 2003; Tang et al., 2009). Another physical method is to apply ultrasound (Holm et al., 2008). Zooplankton and phytoplankton also decrease when heated water is added to the ballast water tanks in ships (Acomi et al., 2012; Avenue and Wales, 1999; Bolch and Hallegraeff, 1993; Hallegraeff et al., 1997; Quilez-Badia et al., 2008). Ozone is widely used for water disinfection but maritime microorganisms have shown resistance (Liltved et al., 2006) and sometimes it causes corrosion (Oemcke and Hans van Leeuwen, 2005; Wu et al., 2011). In this case TiO_2 photo catalysis can be added to the ozone because it is an effective and safe way to destroy bacteria (Benabbou et al., 2007; Yao et al., 2007).

2-2-2- Chemical treatments

Electrochemical oxidation has been applied in recent years over a different range of industrial wastewaters, as well as in disinfection of drinking, swimming pool and seawater. For example, sodium hypochlorite has been shown to be an effective way to destroy bacteria and viruses (Tsolaki et al., 2010). The gas super saturation method causes bubble formation and results in hemorrhagic effects to kill organisms (Takahashi et al., 2001). The use of chemical biocides, in particular seakleen (Granitto, 2006; Stimson et al., 2010), peraclean and the chlorine dioxide biocide vibrex, as a ballast water treatment has restrictions due to value, biological effectiveness and possible

residual toxicity of the discharged ballast water, but Peraclean Ocean appears to have the most potential (de Lafontaine et al., 2008; Gregg and Hallegraeff, 2007). Peroxyacetic acid (PAA) has an ability to sterilize process vessels and tanks to control microbial growth (Profaizer et al., 1997). Chlorine dioxide destroys microorganisms by disruption of the transfer of nutrients through the cell wall, not by disruption of the metabolic process. Stabilized chlorine dioxide is ClO_2 buffered in an aqueous solution (LENNTECH, 2014). Although chlorine dioxide has a half-life of 6–12 hours, it can be safely discharged within 24 hours based on suppliers (Lloyd's Register Group, 2007).

3- Materials and methods

3-1- Location of study and surveyed material

Khark Island is situated in the northern part of the Gulf. The island has a more or less triangular shape, is about 4 miles in length with an average of 2 miles in width. Khark Island's oil terminal is one of the biggest oil terminals in the world. Khark Island provides a seaport for exporting petroleum and oil products (Norouzifard, 2011). There are two different types of ports in Khark Island (Norouzifard, 2011): i) for oil tanker belows 500 000 dead weight (DWT); and ii) for vessels above 500 000 dead weight (DWT).

3-2- Survey of oil tankers

More than 796 ballast water reports of oil tanker by pilot office of Ports & Maritime Organization in the Gulf, collected over an eight month period from 31.10.2012 to 25.06.2013, was checked, of which 356 were without ballast water on boards. The remaining 440 oil tankers carried ballast water and discharged 617,625,754 cubic meters into the Gulf from other ports. The origin and quantity of ballast water discharged by these 440 oil tankers are listed in Table 1. Based on the

ballast water report forms, the most common last port before reaching the port in the south of Iran were, in order of number of oil tankers, UAE, India, Saudi Arabia, and Japan as shown in Table 1.

Table 1: Detail on origin of oil tanker and the amount of Ballast Water discharged (Reports form of investigation of Pilot Office of Ports & Maritime Organization in Khark Island)

3-3- Oil tankers selected for analysis

In this project, 14 oil tankers were selected based on their type of management and inspected. Out of these, samples for the physicochemical analysis were taken from 9 suitable vessels of various types ranging from small cargo vessels with dead weight of <1,000 tons to Very Large Crude Carriers (VLCCs) of >300,000 tons dead weight. Their combined quantity of ballast water was found to be 600,382 tons and the origin of most of them were Asian countries, and their respective capacity, type of management, and port of origin is shown in Table II. Both treatment and exchange were done in oil tankers number 8 and 9 from Japan and China respectively. Two other selected oil tankers -number 7 from Taiwan and number 6 from UAE- have got only treatment without exchange on their ballast water. As shown on Table 2, the rest of the oil tanker exchanged the ballast water three times in the ocean.

Table 2: Specification of 9 oil tankers sampled in Khark Island

3-4- Sampling of Ballast Water

Standard ballast water system methods based on the protocol of MEPC. 173 (58) were used for sampling and analysis of ballast water, which is one of the ways to assess the ballast water management requirements (International Maritime Organization, 2008). Sampling can be divided

into in-tank and in-line sampling. In-tank sampling points provide a way for ballast water to access directly from a tank either via ballast tank manholes, sounding or air pipes. In-line sampling points comprise of the ships ballast water pumps and ship's pipe work (Consult, 2013) and has been used in a number of previous studies (David and Perkovič, 2004; David et al., 2007; Gollasch, 1996; Rosenthal et al., 1999). This project made use of the in-tank sampling method, in which three samples were taken from a manhole.

The ballast water was pumped from the on-board tanks with a speed of 2 litre per minute through pipes with a net diameter of 25 centimeters into a *Point-Source Sampler* through a valve with an opening of 3 millimetres. The time needed to fill-up the sampler was approximately 1 minute. From this, a mesh of 20 microns in the square dimension, which results in a diagonal diameter of 50 microns, was used to filter about 300 litre of ballast water. This was then distributed for the analysis into 250 ml beakers before buffered formalin 37% was added. These samples were then stored in a dark place until the analysis in the laboratory. Sampling of the ballast water for oil tankers of 1,2,3,8, and 9 had been done in spring, while the sampling of oil tankers with the number of 4, 5, 6, and 7 had been done in summer as it is mentioned in Table 2.

3-5- Sampling of seawater

Samples of seawater were taken from different parts of the Gulf three times in different seasons. This sampling was done with a speed of 1.6 litre per minute. A sea strainer with 2-inch diameter inlet and outlet removed larger debris from the water to protect pumps. A sampling technician had to turn it on and off to remove and replace the snare materials where particular care had to be taken to ensure that the seawater would not adversely affect the safety of other operations. Oleophilic snare or oleophilic pad were used to measure the oil content within the porous strainer or basket (Research and planning group, 2006). In the same way as the ballast water samples, around 300

litre of seawater were filtered, distributed into 250 ml beakers and stabilised with formalin for storage and analysis.

3-6- Physicochemical characterisation of samples

The purpose of sampling was to measure the average of temperature, the average of salinity, the average of dissolved oxygen, PAHs, and the average concentration of trace metals in ballast water, seawater, and sea sediment of Khark Island. The equipment and standard methods that were used in identifying physical and chemical parameters are shown in Table III. Most bacteria grow best when measured parameters are optimum for that strain, in the real world microbes can expect frequent environmental changes. In fact, some bacteria have evolved to thrive in environments that are inhospitable for most life. The temperature (°C), salinity and dissolved oxygen were measured on-board at the time of sampling, but the other parameters were subsequently determined in the laboratory.

Table 3: Equipment and standard method of used in identifying physical and chemical parameters

4- Results

The results show the comparison of the temperature, salinity, dissolved oxygen, polycyclic aromatic hydrocarbons (PAHs), trace of heavy metals in ballast water of 9 oil tankers and seawater of the Gulf.

4-1 Temperature

Fig. 1 shows the fluctuations in the seawater temperature of Khark Island through the four seasons; it ranges from 18.5 °C in winter to 33 °C in summer with an average of 25 °C in autumn and spring.

Fig. 1: Average of seawater temperature in Khark Island

Fig. 2 shows that the temperature of the ballast water varied from 22 °C (oil tanker number 8 Japan) to 34 °C (oil tankers number 4 & 6 from India and UAE respectively). This suggests that the temperature tends to be higher the shorter the journey. For tankers from the same port of origin, there is a trend for those tankers with a smaller capacity or smaller amount of ballast water discharge to have a higher temperature.

Fig. 2: Ballast water temperature of oil tankers (number of each tanker is given in Table 2)

4-2 Salinity

Fig. 5 shows that the salinity of the seawater changes from 32 ppt in winter to 41 ppt in summer, with an annual mean of 37.7 ppt. The increase in the summer is due to increased evaporation at the higher temperatures.

Fig. 3: Average of seawater salinity in Khark Island

Fig. 6 also shows a correlation between temperature and salinity, in that oil tankers that have higher temperature also have higher salinity. The difference between the oil tanker with the highest salinity, 35 ppt for number 6 from the UAE and that with the lowest salinity, 25 ppt from Japan, is of the same magnitude as the summer-winter difference of the seawater but the absolute level of salinity is substantially smaller than that of the seawater around Khark Island with only 31.2 ppt.

Fig. 4: Ballast water salinity of oil tankers

4-3 Dissolved Oxygen

Bacteria, namely aerobes, are those that require oxygen for growth and only make energy from respiration. Fig. 5 shows the oxygen content of seawater changes: it ranges from 4.6 milligram per litre in summer to 7.8 milligram per litre in winter, with 5.8 milligram per litre in fall and spring.

Fig. 5: Average of seawater dissolved oxygen concentration in Khark Island

Fig. 4 shows the result of the dissolved oxygen in ballast water. It is noticed that there is a large differences between 3.8 milligram per litre in oil tanker number 8 from Japan and 6.8 milligram per litre in oil tanker number 6 from UAE due to the differences in distance and consequently consuming more oxygen in longer distance. Oil tankers with different capacity have the same dissolved oxygen.

Fig. 6: Ballast water dissolved oxygen concentration of oil tankers

4-4 Heavy metals

Heavy metals can enter the environment through wastewater and ballast water. Figs. 7, 8 and 9 show the trend of Co, Ni, and Cr in ballast water, while Fig. 10 shows the average concentration of heavy metals in the sea sediment of Khark Island. The amount of heavy metals contained in the ballast water depends mainly on the type of ballast water management. For example, oil tanker number 9 from China has the least trace metals due to the combination of ballast water exchange and chemical treatment, while oil tanker number 8 from Japan was second because of using ballast water exchange and physical treatment. These were followed by number 6 from UAE and number 7 from Taiwan which used only chemical treatment. Finally, oil tankers that used only ballast water exchange had more heavy metals than the others. In the case of oil tankers using the same ballast water management strategy, there were still differences in heavy metals contained in the ballast water because of distance between departure and arrival port, capacity, and weight of oil tankers. The result of heavy metal of the oil tanker from UAE that used only chemical treatment was so close to the result of oil tanker from Japan that used exchange and physical treatment because oil tanker number 6 from UAE was so close to arrival port that it did not need to have ballast water exchange. It is noteworthy that oil tankers from the same departure port seem to have more trace metals if they have a higher capacity. Individual findings for each trace metal are summarised in the following paragraphs.

The concentration of cobalt, Co, in seawater changed between 0.008 milligram per litre and 5 milligram per litre in different seasons. In contrast, Co in the ballast water varied less, with a minimum amount of 1.9 milligram per litre for oil tanker number 9 from China and the maximum amount of 5 milligram per litre for oil tanker numbers 4 and 1 from India and China, respectively (Fig. 7).

Nickel, Ni, had such a low concentration in the seawater that it never increased above the minimum resolution of the instrument (<0.004 milligram per litre) whereas it varied in the ballast water between 0.004 (oil tanker number 9 from China) and 0.029 milligram per litre (oil tanker number 2 from Singapore) (Fig. 8).

Similarly, chromium, Cr, in seawater was always below the sensitivity of the instrument (<1 milligram per litre) but was found the ballast water to be between 0.7 milligram per litre in oil tanker number 9 from China and 2.1 milligram per litre in oil tanker number 5 from India (Fig. 9).

Lead, Pb, was never observed in either seawater or ballast water to within the limitation of measurement (<0.01 milligram per litre), nor was oil (<0.02 milligram per litre).

Fig. 7: Ballast water Co concentration of oil tankers

Fig. 8: Ballast water Ni concentration of oil tankers

Fig. 9: Ballast water Cr concentration of oil tankers

Results of trace metals in sea sediments are also shown in Fig. 10. The mean concentration of Co, Cr, Ni and Pb in sea sediment in Khark Island is 13.95, 8.65, 23.55 and 27.15 milligram per litre respectively.

Fig. 10: Average of sea sediment trace metals concentration in Khark Island

4-5 Polycyclic aromatic hydrocarbons (PAHs)

Fig. 11 shows the concentration of the PAHs compound in ballast water, seawater and sea sediment respectively. No PAHs were recorded in the seawater samples, presumably because it is less buoyant than water. The highest concentration of PAHs in ballast water was found in oil tanker number 6 from UAE with 2 microgram per litre, closely followed by oil tanker number 1 from China, as can be seen in Fig. 11. All others had a concentration between 1 and 1.5 microgram per litre with oil tanker number 3 from Singapore having the least with 1 microgram per litre. A concentration of sea sediment PAHs equal to 0.0054 milligram per litre.

Fig.11: Ballast water PAHs concentration of oil tankers

5-Discussion

Results show physical and chemical characteristic of ballast water is not in the range of sea sediment, specifically for the ships from India that shows a different condition of water in the Gulf and Indian Ocean. For example, in heavy metals, the result of Ni in ballast water (oil tanker number 2 from Singapore) is 0.029 which is higher than sea sediment (0.004) or the value of Cr in ballast water is 2.1 (oil tanker number 5 from India) that is higher than the limitation (less than 1 mg/litre). However, there are no huge differences in PAHs of ballast water and sea sediment. Salting of ballast water is 36 ppt (Density of 1.025) which is between results of sea sediment (32 ppt and 41 ppt with density of 1.031). The dissolved oxygen of ballast water is less than sea sediment; hence the number of aerobic beings in ballast water is less than sea sediment.

At the time of researching, most of the oil tanker used to come from Asian countries that have the close physiochemical to the Gulf. It is impossible to do anything about what happened in past, but it is possible to manage ballast water and prevent this from any hazardous to happen in the future.

The previous section presented the results for each physicochemical analysis in turn. Here, we will highlight some key correlations to aid with the interpretation of the findings using Pearson's correlation coefficient. The very high correlation between temperature and salinity ($r= 0.940$) has already been pointed out but there is also a correlation to dissolved oxygen, where the correlation of DO to salinity with $r= 0.782$ is better than that between DO and temperature ($r= 0.767$). In addition to this, the distance travelled emerges as an important factor highly correlated to DO ($r= 0.988$), salinity ($r= 0.820$) and temperature ($r= 0.804$), respectively. The correlation of salinity to port of origin is shown in Fig. 12 which suggests a decrease in salinity from the nearest port in the UAE to the most distant port in Japan with only one exception for the oil tanker from Taiwan.

Fig. 12: Salinity of ballast water against origin. Countries of origin with a single tanker are shown as a horizontal line. Countries with two tankers show the two salinity results as the upper and lower limit of the box and the average as the horizontal line.

The amount of dissolved oxygen (DO) shows a very clear decrease with distance to the origin, as illustrated in Fig. 13, where the measurements from the same origin were identical for all three pairs sampled, irrespective of ballast water management. While this might be linked to the conditions at the point of departure, it is more likely to be a consequence of the duration of the voyages. The longer the voyage lasts, the more oxygen is consumed by aerobes present and the less remained at the time of sampling. A final observation before considering heavy metals is that

the amount of PAHs in the ballast water shows a clear correlation with volume of ballast water exchanged ($r= 0.748$).

Fig. 13: Salinity of ballast water against origin. Countries of origin with a single tanker are shown as a horizontal line. Countries with two tankers show the two salinity results as the upper and lower limit of the box and the average as the horizontal line.

The presence of heavy metals is most strongly affected by the ballast water management used. This is illustrated in Fig. 14 for cobalt as an example, where water exchange only consistently returned the highest concentrations for cobalt. This was followed by chemical treatment alone, and then the combination of water exchange and physical treatment. The lowest concentration was found after water exchange complemented with chemical treatment. The results for chromium were qualitatively identical but nickel was somewhat unusual. The management consisting of water exchange only spanned the entire range from lowest to highest concentration across all nine oil tankers. The nickel concentration for the other three management methods, however, showed the same trend as for Co and Cr.

Fig. 14: Concentration of cobalt in the ballast water against ballast water management method.

The heavy metal concentration found in the sediment compared favourably to other recent surveys in the Gulf (Youssefa et al., 2015) suggesting that there is currently no cause for concern for the ecosystems around Khark Island. However, the concentrations of heavy metals in the ballast water

were in most cases significantly above those of the sea sediment samples that indicate that ballast water is a source of heavy metals when it is exchanged with the local sea sediment. This suggests that effective ballast water management is important to maintain the local sea sediment quality. Given the limited sample of this study, one can only conclude that either water exchange alone or chemical treatment alone is not effective to protect the environment from heavy metal pollution but that the combination of water exchange with either physical or chemical treatment is recommended. To explore the most effective treatment, one should now refine this study with more targeted sampling of vessels employing a variety of treatment. For example, one of the promising methods would be the UV/Ag-TiO₂/O₃, which was proven to be efficient for *D. salina* inactivation and has higher treatment efficiency than using one of these methods alone (Wu et al., 2011). One additional measure to reduce local pollution would be to carry out ballast water exchange several times during voyage to have water more similar to the destination water.

6- Conclusion

This study investigated the effect of different methods of ballast water management and port of origin for a selection of oil tankers arriving in Khark Island in the Persian Gulf. The results showed that the salinity and dissolved oxygen (DO) are highly correlated with the distance of the port of origin or duration of voyage, where both salinity and DO decreased substantially with increasing distance. It would therefore seem recommended to carry out ballast water exchanges several times during voyage to ensure that the ballast water salinity and DO are similar to those at the destination. The choice of ballast water management method seemed to have a substantial effect only on the heavy metal concentration of the parameters investigated here. However, given the toxicity of heavy metals, it seems to be strong evidence to consider the most appropriate ballast water management method carefully. The evidence here suggests that ballast water exchange alone is

least reliable in reducing heavy metal concentrations, nor is chemical treatment alone. In contrast, combining water exchange with either physical or chemical treatment appears to be the most reliable choice. Given the scope of this study, it is not yet possible to identify which specific combination is the best. This would be the subject of future work.

(Suna et al., 2000; Yazdanparast et al., 2004; Yellow Spring Instrument Company, n.d., n.d.)

References

- Acomi, N., Popescu, C., Varsami, A.E., Chircor, M., Grosan, V.N., 2012. A new method for treating the ballast water by heating. *Ann. DAAAM* 23, 505–508.
- Airahuobhor, A., 2010. Nigeria: International Collaboration to Protect Marine Environment From Ballast Water [WWW Document]. All africa. URL <http://allafrica.com/stories/201006180445.html>
- Avenue, C., Wales, N.S., 1999. Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Mar. Ecol. Prog. Ser.* 191, 289–293.
- Bai, X., Zhang, Z., Bai, M., Yang, B., Bai, M., 2005. Killing of Invasive Species of Ship's Ballast Water in 20t/h System Using Hydroxyl Radicals. *Plasma Chem. Plasma Process.* 25, 41–54.
- Balasubramanian, S., Ortego, J., Rusch, K., Boldor, D., 2008. Efficiency of *Artemia* cysts removal as a model invasive spore using a continuous microwave system with heat recovery. *Environ. Sci. Technol.* 42, 9363–9369.
- Bax, N., Williamson, A., Agüero, M., Gonzalez, E., Geeves, W., 2003. Marine Invasive Alien Species : A Threat to Global Biodiversity Marine invasive alien species : a threat to global biodiversity. *Mar. Policy* 27, 313–323. doi:10.1016/S0308-597X(03)00041-1
- Benabbou, A.K., Derriche, Z., Felix, C., Lejeune, P., Guillard, C., 2007. Photocatalytic inactivation

- of *Escherichia coli*. Appl. Catal. B Environ. 76, 257–263. doi:10.1016/j.apcatb.2007.05.026
- Bolch, C.J., Hallegraeff, G.M., 1993. Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. J. Mar. Env. Engg. 1, 23–29.
- Consult, D., 2013. Ballast water sampling for compliance monitoring - Ratification of the Ballast Water Management Convention.
- Costello, C., Drake, J.M., Lodge, D.M., 2007. EVALUATING AN INVASIVE SPECIES POLICY : BALLAST WATER EXCHANGE IN THE GREAT LAKES. Ecol. Appl. 17, 655–662.
- David, M., Gollasch, S., 2015. Global Maritime Transport and Ballast Water Management. Springer Netherlands. doi:10.1007/978-94-017-9367-4
- David, M., Gollasch, S., 2008. EU shipping in the dawn of managing the ballast water issue. Mar. Pollut. Bull. 56, 1966–72. doi:10.1016/j.marpolbul.2008.09.027
- David, M., Gollasch, S., Cabrini, M., Perkovič, M., Bošnjak, D., Virgilio, D., 2007. Results from the first ballast water sampling study in the Mediterranean Sea - the Port of Koper study. Mar. Pollut. Bull. 54, 53–65. doi:10.1016/j.marpolbul.2006.08.041
- David, M., Perkovič, M., 2004. Ballast water sampling as a critical component of biological invasions risk management. Mar. Pollut. Bull. 49, 313–318. doi:10.1016/j.marpolbul.2004.02.022
- de Lafontaine, Y., Despatie, S.-P., Wiley, C., 2008. Effectiveness and potential toxicological impact of the PERACLEAN Ocean ballast water treatment technology. Ecotoxicol. Environ. Saf. 71, 355–69. doi:10.1016/j.ecoenv.2007.10.033
- Delacroix, S., Vogelsang, C., Tobiesen, A., Liltved, H., 2013. Norsk institutt for vannforskning Article Disinfection by-products and ecotoxicity of ballast water after oxidative treatment –

- Results and experiences from seven years of full-scale testing of ballast water management systems . Stephanie Delacroix Norweg. *Mar. Pollut. Bull.* 73, 24–36.
- Dunstan, P.K., Bax, N.J., 2008. Management of an invasive marine species : defining and testing the effectiveness of ballast-water management options using management strategy evaluation. *ICES J. Mar. Sci. Adv.* 65, 841–850.
- Firestone, J., Corbett, J.J., 2006. Coastal and Port Environments: International Legal and Policy Responses to Reduce Ballast Water Introductions of Potentially Invasive Species. *Ocean Fish. Law* 7, 45–49.
- Gavand, M.R., McClintock, J.B., Amsler, C.D., Peters, R.W., Angus, R. a, 2007. Effects of sonication and advanced chemical oxidants on the unicellular green alga *Dunaliella tertiolecta* and cysts, larvae and adults of the brine shrimp *Artemia salina*: a prospective treatment to eradicate invasive organisms from ballast water. *Mar. Pollut. Bull.* 54, 1777–88. doi:10.1016/j.marpolbul.2007.07.012
- Germanischer Lloyd SE, 2013. Rules for Classification and Construction: Additional Rules and Guidelines, in: Guidelines on Ballast Water Management. Germanischer Lloyd SE, p. 13.
- Gollasch, S., 2006. Overview on introduced aquatic species in European navigational and adjacent waters 84–89. doi:10.1007/s10152-006-0022-y
- Gollasch, S., 2004. IMO Ballast Water Convention.
- Gollasch, S., 1996. Untersuchungen des Artbeitrages durch den internationalen Schiffsverkehr unter besonderer Berücksichtigung nichteinheimischer Arten. Verlag Dr. Kovac.
- Gonçalves, A.A., Gagnon, G.A., 2012. Recent Technologies for Ballast Water Treatment. *Ozone Sci. Eng.* 34, 174–195. doi:10.1080/01919512.2012.663708
- Govind, P., Madhuri, S., 2014. Heavy Metals Causing Toxicity in Animals and Fishes. *Res. J.*

- Anim. Vet. Fish. Sci. 2, 17–23.
- Granitto, M., 2006. Two Ballast Water Treatment Technologies Parallel Path.
- Gregg, M.D., Hallegraeff, G.M., 2007. Efficacy of three commercially available ballast water biocides against vegetative microalgae, dinoflagellate cysts and bacteria. *Harmful Algae* 6, 567–584. doi:10.1016/j.hal.2006.08.009
- Hallegraeff, G.M., Valentine, J.P., Marshall, J., Bolch, C.J., 1997. Temperature tolerances of toxic dinoflagellate cysts : application to the treatment of ships ' ballast water. *Aquat. Ecol.* 31, 47–52.
- Hellyer, P., Aspinall, S., 2005. *The Emirates: A Natural History*. Trident Press.
- Holm, E.R., Stamper, D.M., Brizzolara, R. a, Barnes, L., Deamer, N., Burkholder, J.M., 2008. Sonication of bacteria, phytoplankton and zooplankton: Application to treatment of ballast water. *Mar. Pollut. Bull.* 56, 1201–8. doi:10.1016/j.marpolbul.2008.02.007
- International Maritime Organization, I.M.O., 2016. Status of conventions [WWW Document]. URL [www.imo.org/About/Conventions/StatusOfConventions/Documents/Summary of Status of Conventions.xls](http://www.imo.org/About/Conventions/StatusOfConventions/Documents/Summary_of_Status_of_Conventions.xls)
- International Maritime Organization, I.M.O., 2008. RESOLUTION MEPC.173(58), GUIDELINES FOR BALLAST WATER SAMPLING (G2) [WWW Document]. URL [http://www.imo.org/blast/blastDataHelper.asp?data_id=23757&filename=173\(58\).pdf](http://www.imo.org/blast/blastDataHelper.asp?data_id=23757&filename=173(58).pdf)
- LENNTECH, 2014. Chlorine dioxide [WWW Document]. *Water Treat. Solut.* URL http://www.lenntech.com/library/clo2/chlorine-dioxide.htm?gclid=CJm-4ZGfnb8CFQb3wgod_KoACg#ixzz35xjekRBG
- Liltved, H., Tobiessen, A., Delacroix, S., Heiaas, H., Tryland, I., 2011. Filtration and UV treatment for ships ' ballast water management – water quality challenges and UV-dose requirements.

- Liltved, H., Vogelsang, C., Modahl, I., Dannevig, B.H., 2006. High resistance of fish pathogenic viruses to UV irradiation and ozonated seawater. *Aquac. Eng.* 34, 72–82. doi:10.1016/j.aquaeng.2005.05.002
- Lloyd's Register Group, 2007. Ballast Water Treatment Technology.
- Lloyd's Register Group, L., 2010. Ballast water management.
- Nanayakkara, K.G.N., Zheng, Y., Alam, A.K.M.K., Zou, S., Chen, J.P., 2011. Electrochemical disinfection for ballast water management: Technology development and risk assessment. *Mar. Pollut. Bull.* 63, 119–123. doi:10.1016/j.marpolbul.2011.03.003
- Nasser, A., Huberman, Z., Dean, L., Bonner, F., Adin, A., 2002. Coagulation as a pretreatment of SFBW for membrane filtration. *Water Sci. Technol. water supply* 2, 301–306.
- Ngoka, M., 2015. Removal of Barriers to the Effective Implementation of Ballast Water Control and Management Measures in Developing Countries [WWW Document]. *Int. waters Learn. Exch. Resour. Netw.* URL <http://iwlearn.net/iw-projects/610>
- Norouzifard, M., 2011. Oil Facilities in Kharg Island [WWW Document]. *Payvand Iran News.* URL <http://www.payvand.com/news/11/oct/1228.html>
- Oemcke, D.J., Hans van Leeuwen, J., 2005. Ozonation of the marine dinoflagellate alga *Amphidinium* sp.--implications for ballast water disinfection. *Water Res.* 39, 5119–25. doi:10.1016/j.watres.2005.09.024
- Panetta, L.E., 2003. America's living oceans: charting a course for sea change [WWW Document]. *Pew Ocean. Comm.* URL http://www.pewtrusts.org/~media/assets/2003/06/02/full_report.pdf?la=en
- Perakis, A.N., Yang, Z., 2003. Options for Nonindigenous Species Control and Their Economic Impact on the Great Lakes and St . Lawrence Seaway : A Survey. *Mar. Technol.* 40, 34–41.

- Profaizer, M., Massone, A., Nurizzo, C., Bandera, F., 1997. the Behaviour of Peracetic Acid As a Water Disinfectant. Meded. Rijksuniv. Gent. Fak. Landbouwk. Toegep. Biol. Wet. 62, 1785–1792.
- Quilez-Badia, G., McCollin, T., Josefsen, K.D., Vourdachas, A., Gill, M.E., Mesbahi, E., Frid, C.L.J., 2008. On board short-time high temperature heat treatment of ballast water: a field trial under operational conditions. Mar. Pollut. Bull. 56, 127–35. doi:10.1016/j.marpolbul.2007.09.036
- Research and planning group, L., 2006. Methods for sampling Seawater Intakes, in: Water Intakes Sampling Methods. pp. 91–110.
- Romero-martínez, L., Moreno-andrés, J., Acevedo-merino, A., Nebot, E., 2014. Improvement of ballast water disinfection using a photocatalytic (UV-C + TiO_2) flow-through reactor for saltwater treatment. Chem. Technol. Biotechnol. 89, 1203–1210. doi:10.1002/jctb.4385
- Rosenthal, H., Gollasch, S., M., V., 1999. Testing Monitoring Systems for Risk Assessment of harmful Introductions by Ships to European Waters.
- Sharma, P., 2009. Coastal Zone Management. Global India Publications.
- Stehouwer, P.P., Buma, A., Peperzak, L., Paul, P., Buma, A., A, L.P., 2015. A comparison of six different ballast water treatment systems based on UV radiation , electrochlorination and chlorine dioxide. Environ. Technol. 36, 2094–2104. doi:10.1080/09593330.2015.1021858
- Stimson, W., Zhou, P., Vassalos, D., Incecik, A., 2010. Ballast water treatment system.
- Suna, Y.-C., Mierzwab, J., Lan, C.-R., 2000. Direct determination of molybdenum in seawater by adsorption cathodic stripping square-wave voltammetry. Talanta 52, 417–424.
- Takahashi, C.M., Gianni, K., Lima, D.C., 2001. Fermentation of sugar cane bagasse hemicellulosic hydrolysate and sugar mixtures to ethanol by recombinant Escherichia coli KO11.

- Tang, Z., Butkus, M.A., Xie, Y.F., 2009. Enhanced performance of crumb rubber filtration for ballast water treatment. *Chemosphere* 74, 1396–1399. doi:10.1016/j.chemosphere.2008.11.048
- Tootsie, K.M., 2002. The Environmental Impacts of Port and Harbour Activities: Ballast Water Management. Univ. Hong Kong. doi:10.1017/CBO9781107415324.004
- Tsolaki, E., Diamadopoulos, E., 2010. Technologies for ballast water treatment : a review. *J. Chem. Technol. Biotechnol.* 85, 19–32. doi:10.1002/jctb.2276
- Tsolaki, E., Pitta, P., Diamadopoulos, E., 2010. Electrochemical disinfection of simulated ballast water using *Artemia salina* as indicator. *Chem. Eng. J.* 156, 305–312. doi:10.1016/j.cej.2009.10.021
- UNEP, 1999. Overview on Land-based Sources and Activities Affecting the Marine Environment in the ROPME Sea Area.
- Werschkun, B., Banerji, S., Basurko, O.C., David, M., Fuhr, F., Gollasch, S., Grummt, T., Haarich, M., Jha, A.N., Kacan, S., Kehrer, A., Linders, J., Mesbahi, E., Pughiuc, D., Richardson, S.D., Schwarz-schulz, B., Shah, A., Theobald, N., Gunten, U. Von, Wieck, S., Höfer, T., 2014. Chemosphere Emerging risks from ballast water treatment : The run-up to the International Ballast Water Management Convention. *Chemosphere* 112, 256–266. doi:10.1016/j.chemosphere.2014.03.135
- Williams, S.L., Grosholz, E.D., 2008. The Invasive Species Challenge in Estuarine and Coastal Environments : Marrying Management and Science 3–20. doi:10.1007/s12237-007-9031-6
- Wu, D., You, H., Du, J., Chen, C., Jin, D., 2011. Effects of UV/Ag-TiO₂/O₃ advanced oxidation on unicellular green alga *Dunaliella salina*: implications for removal of invasive species from ballast water. *J. Environ. Sci.* 23, 513–519.
- Yao, K.S., Wang, D.Y., Ho, W.Y., Yan, J.J., Tzeng, K.C., 2007. Photocatalytic bactericidal effect

- of TiO₂ thin film on plant pathogens. *Surf. Coatings Technol.* 201, 6886–6888.
doi:10.1016/j.surfcoat.2006.09.068
- Yazdanparast, F., Nouri, A., Rabbani, M., 2004. Identification and determination of PAHs compounds in Anzali International Wetland. *Int. J. Environ. Sci. Technol.* 1, 215–220.
- Yellow Spring Instrument Company, Y., n.d. YSI model 33 S-C-T meter [WWW Document]. URL https://www.ysi.com/File_Library/Documents/Manuals_for_Discontinued_Products/33-S-C-T-Meter.pdf
- Yellow Spring Instrument Company, Y., n.d. Instruction manual YSI model 57 [WWW Document]. URL https://www.ysi.com/File_Library/Documents/Manuals_for_Discontinued_Products/57-Dissolved-Oxygen-Meter.pdf
- Zhang, Z., Bai, M.D., Yang, B., Mindi, B., Xiyao, B., 2005. Treatment of Invasive Marine Species on Board by Using Micro-gap Discharge Plasma *. *Plasma Sci. Technol.* 7, 3025–3029.
- Acomi, N., Popescu, C., Varsami, A.E., Chircor, M., Grosan, V.N., 2012. A new method for treating the ballast water by heating. *Ann. DAAAM* 23, 505–508.
- Airahuobhor, A., 2010. Nigeria: International Collaboration to Protect Marine Environment From Ballast Water [WWW Document]. All africa. URL <http://allafrica.com/stories/201006180445.html>
- Avenue, C., Wales, N.S., 1999. Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Mar. Ecol. Prog. Ser.* 191, 289–293.
- Bai, X., Zhang, Z., Bai, M., Yang, B., Bai, M., 2005. Killing of Invasive Species of Ship's Ballast Water in 20t/h System Using Hydroxyl Radicals. *Plasma Chem. Plasma Process.* 25, 41–54.

- Balasubramanian, S., Ortego, J., Rusch, K., Boldor, D., 2008. Efficiency of *Artemia* cysts removal as a model invasive spore using a continuous microwave system with heat recovery. *Environ. Sci. Technol.* 42, 9363–9369.
- Bax, N., Williamson, A., Agüero, M., Gonzalez, E., Geeves, W., 2003. Marine Invasive Alien Species : A Threat to Global Biodiversity Marine invasive alien species : a threat to global biodiversity. *Mar. Policy* 27, 313–323. doi:10.1016/S0308-597X(03)00041-1
- Benabbou, A.K., Derriche, Z., Felix, C., Lejeune, P., Guillard, C., 2007. Photocatalytic inactivation of *Escherichia coli*. *Appl. Catal. B Environ.* 76, 257–263. doi:10.1016/j.apcatb.2007.05.026
- Bolch, C.J., Hallegraeff, G.M., 1993. Chemical and physical treatment options to kill toxic dinoflagellate cysts in ships' ballast water. *J. Mar. Env. Engg.* 1, 23–29.
- Consult, D., 2013. Ballast water sampling for compliance monitoring - Ratification of the Ballast Water Management Convention.
- Costello, C., Drake, J.M., Lodge, D.M., 2007. EVALUATING AN INVASIVE SPECIES POLICY : BALLAST WATER EXCHANGE IN THE GREAT LAKES. *Ecol. Appl.* 17, 655–662.
- David, M., Gollasch, S., 2015. Global Maritime Transport and Ballast Water Management. Springer Netherlands. doi:10.1007/978-94-017-9367-4
- David, M., Gollasch, S., 2008. EU shipping in the dawn of managing the ballast water issue. *Mar. Pollut. Bull.* 56, 1966–72. doi:10.1016/j.marpolbul.2008.09.027
- David, M., Gollasch, S., Cabrini, M., Perkovič, M., Bošnjak, D., Virgilio, D., 2007. Results from the first ballast water sampling study in the Mediterranean Sea - the Port of Koper study. *Mar. Pollut. Bull.* 54, 53–65. doi:10.1016/j.marpolbul.2006.08.041
- David, M., Perkovič, M., 2004. Ballast water sampling as a critical component of biological

- invasions risk management. *Mar. Pollut. Bull.* 49, 313–318.
doi:10.1016/j.marpolbul.2004.02.022
- de Lafontaine, Y., Despatie, S.-P., Wiley, C., 2008. Effectiveness and potential toxicological impact of the PERACLEAN Ocean ballast water treatment technology. *Ecotoxicol. Environ. Saf.* 71, 355–69. doi:10.1016/j.ecoenv.2007.10.033
- Delacroix, S., Vogelsang, C., Tobiesen, A., Liltved, H., 2013. Norsk institutt for vannforskning
Article Disinfection by-products and ecotoxicity of ballast water after oxidative treatment –
Results and experiences from seven years of full-scale testing of ballast water management
systems . Stephanie Delacroix Norweg. *Mar. Pollut. Bull.* 73, 24–36.
- Dunstan, P.K., Bax, N.J., 2008. Management of an invasive marine species : defining and testing
the effectiveness of ballast-water management options using management strategy evaluation.
ICES J. Mar. Sci. Adv. 65, 841–850.
- Firestone, J., Corbett, J.J., 2006. Coastal and Port Environments: International Legal and Policy
Responses to Reduce Ballast Water Introductions of Potentially Invasive Species. *Ocean Fish.
Law* 7, 45–49.
- Gavand, M.R., McClintock, J.B., Amsler, C.D., Peters, R.W., Angus, R. a, 2007. Effects of
sonication and advanced chemical oxidants on the unicellular green alga *Dunaliella tertiolecta*
and cysts, larvae and adults of the brine shrimp *Artemia salina*: a prospective treatment to
eradicate invasive organisms from ballast water. *Mar. Pollut. Bull.* 54, 1777–88.
doi:10.1016/j.marpolbul.2007.07.012
- Germanischer Lloyd SE, 2013. Rules for Classification and Construction: Additional Rules and
Guidelines, in: Guidelines on Ballast Water Management. Germanischer Lloyd SE, p. 13.
- Gollasch, S., 2006. Overview on introduced aquatic species in European navigational and adjacent

- waters 84–89. doi:10.1007/s10152-006-0022-y
- Gollasch, S., 2004. IMO Ballast Water Convention.
- Gollasch, S., 1996. Untersuchungen des Artbeitrages durch den internationalen Schiffsverkehr unter besonderer Berücksichtigung nichteinheimischer Arten. Verlag Dr. Kovac.
- Gonçalves, A.A., Gagnon, G.A., 2012. Recent Technologies for Ballast Water Treatment. *Ozone Sci. Eng.* 34, 174–195. doi:10.1080/01919512.2012.663708
- Govind, P., Madhuri, S., 2014. Heavy Metals Causing Toxicity in Animals and Fishes. *Res. J. Anim. Vet. Fish. Sci.* 2, 17–23.
- Granitto, M., 2006. Two Ballast Water Treatment Technologies Parallel Path.
- Gregg, M.D., Hallegraeff, G.M., 2007. Efficacy of three commercially available ballast water biocides against vegetative microalgae, dinoflagellate cysts and bacteria. *Harmful Algae* 6, 567–584. doi:10.1016/j.hal.2006.08.009
- Hallegraeff, G.M., Valentine, J.P., Marshall, J., Bolch, C.J., 1997. Temperature tolerances of toxic dinoflagellate cysts : application to the treatment of ships ' ballast water. *Aquat. Ecol.* 31, 47–52.
- Hellyer, P., Aspinall, S., 2005. *The Emirates: A Natural History*. Trident Press.
- Holm, E.R., Stamper, D.M., Brizzolara, R. a, Barnes, L., Deamer, N., Burkholder, J.M., 2008. Sonication of bacteria, phytoplankton and zooplankton: Application to treatment of ballast water. *Mar. Pollut. Bull.* 56, 1201–8. doi:10.1016/j.marpolbul.2008.02.007
- International Maritime Organization, I.M.O., 2016. Status of conventions [WWW Document]. URL [www.imo.org/About/Conventions/StatusOfConventions/Documents/Summary of Status of Conventions.xls](http://www.imo.org/About/Conventions/StatusOfConventions/Documents/Summary_of_Status_of_Conventions.xls)
- International Maritime Organization, I.M.O., 2008. RESOLUTION MEPC.173(58), GUIDELINES

- FOR BALLAST WATER SAMPLING (G2) [WWW Document]. URL [http://www.imo.org/blast/blastDataHelper.asp?data_id=23757&filename=173\(58\).pdf](http://www.imo.org/blast/blastDataHelper.asp?data_id=23757&filename=173(58).pdf)
- LENNTECH, 2014. Chlorine dioxide [WWW Document]. Water Treat. Solut. URL http://www.lenntech.com/library/clo2/chlorine-dioxide.htm?gclid=CJm-4ZGfmb8CFQb3wgod_KoACg#ixzz35xjekRBG
- Liltved, H., Tobiessen, A., Delacroix, S., Heiaas, H., Tryland, I., 2011. Filtration and UV treatment for ships ' ballast water management – water quality challenges and UV-dose requirements.
- Liltved, H., Vogelsang, C., Modahl, I., Dannevig, B.H., 2006. High resistance of fish pathogenic viruses to UV irradiation and ozonated seawater. *Aquac. Eng.* 34, 72–82. doi:10.1016/j.aquaeng.2005.05.002
- Lloyd's Register Group, 2007. Ballast Water Treatment Technology.
- Lloyd's Register Group, L., 2010. Ballast water management.
- Nanayakkara, K.G.N., Zheng, Y., Alam, A.K.M.K., Zou, S., Chen, J.P., 2011. Electrochemical disinfection for ballast water management: Technology development and risk assessment. *Mar. Pollut. Bull.* 63, 119–123. doi:10.1016/j.marpolbul.2011.03.003
- Nasser, A., Huberman, Z., Dean, L., Bonner, F., Adin, A., 2002. Coagulation as a pretreatment of SFBW for membrane filtration. *Water Sci. Technol.* water supply 2, 301–306.
- Ngoka, M., 2015. Removal of Barriers to the Effective Implementation of Ballast Water Control and Management Measures in Developing Countries [WWW Document]. *Int. waters Learn. Exch. Resour. Netw.* URL <http://iwlearn.net/iw-projects/610>
- Norouzifard, M., 2011. Oil Facilities in Kharg Island [WWW Document]. *Payvand Iran News.* URL <http://www.payvand.com/news/11/oct/1228.html>
- Oemcke, D.J., Hans van Leeuwen, J., 2005. Ozonation of the marine dinoflagellate alga

- Amphidinium sp.--implications for ballast water disinfection. *Water Res.* 39, 5119–25.
doi:10.1016/j.watres.2005.09.024
- Panetta, L.E., 2003. America's living oceans: charting a course for sea change [WWW Document].
Pew Ocean. Comm. URL
http://www.pewtrusts.org/~media/assets/2003/06/02/full_report.pdf?la=en
- Perakis, A.N., Yang, Z., 2003. Options for Nonindigenous Species Control and Their Economic Impact on the Great Lakes and St . Lawrence Seaway : A Survey. *Mar. Technol.* 40, 34–41.
- Profaizer, M., Massone, A., Nurizzo, C., Bandera, F., 1997. the Behaviour of Peracetic Acid As a Water Disinfectant. *Meded. Rijksuniv. Gent. Fak. Landbouwk. Toegep. Biol. Wet.* 62, 1785–1792.
- Quilez-Badia, G., McCollin, T., Josefsen, K.D., Vourdachas, A., Gill, M.E., Mesbahi, E., Frid, C.L.J., 2008. On board short-time high temperature heat treatment of ballast water: a field trial under operational conditions. *Mar. Pollut. Bull.* 56, 127–35.
doi:10.1016/j.marpolbul.2007.09.036
- Research and planning group, L., 2006. Methods for sampling Seawater Intakes, in: *Water Intakes Sampling Methods*. pp. 91–110.
- Romero-martínez, L., Moreno-andrés, J., Acevedo-merino, A., Nebot, E., 2014. Improvement of ballast water disinfection using a photocatalytic (UV-C + TiO₂) flow-through reactor for saltwater treatment. *Chem. Technol. Biotechnol.* 89, 1203–1210. doi:10.1002/jctb.4385
- Rosenthal, H., Gollasch, S., M., V., 1999. Testing Monitoring Systems for Risk Assessment of harmful Introductions by Ships to European Waters.
- Sharma, P., 2009. Coastal Zone Management. Global India Publications.
- Stehouwer, P.P., Buma, A., Peperzak, L., Paul, P., Buma, A., A, L.P., 2015. A comparison of six

- different ballast water treatment systems based on UV radiation , electrochlorination and chlorine dioxide. *Environ. Technol.* 36, 2094–2104. doi:10.1080/09593330.2015.1021858
- Stimson, W., Zhou, P., Vassalos, D., Incecik, A., 2010. Ballast water treatment system.
- Suna, Y.-C., Mierzwab, J., Lan, C.-R., 2000. Direct determination of molybdenum in seawater by adsorption cathodic stripping square-wave voltammetry. *Talanta* 52, 417–424.
- Takahashi, C.M., Gianni, K., Lima, D.C., 2001. Fermentation of sugar cane bagasse hemicellulosic hydrolysate and sugar mixtures to ethanol by recombinant *Escherichia coli* KO11.
- Tang, Z., Butkus, M.A., Xie, Y.F., 2009. Enhanced performance of crumb rubber filtration for ballast water treatment. *Chemosphere* 74, 1396–1399. doi:10.1016/j.chemosphere.2008.11.048
- Tootsie, K.M., 2002. The Environmental Impacts of Port and Harbour Activities: Ballast Water Management. Univ. Hong Kong. doi:10.1017/CBO9781107415324.004
- Tsolaki, E., Diamadopoulos, E., 2010. Technologies for ballast water treatment : a review. *J. Chem. Technol. Biotechnol.* 85, 19–32. doi:10.1002/jctb.2276
- Tsolaki, E., Pitta, P., Diamadopoulos, E., 2010. Electrochemical disinfection of simulated ballast water using *Artemia salina* as indicator. *Chem. Eng. J.* 156, 305–312. doi:10.1016/j.cej.2009.10.021
- UNEP, 1999. Overview on Land-based Sources and Activities Affecting the Marine Environment in the ROPME Sea Area.
- Werschkun, B., Banerji, S., Basurko, O.C., David, M., Fuhr, F., Gollasch, S., Grummt, T., Haarich, M., Jha, A.N., Kacan, S., Kehrer, A., Linders, J., Mesbahi, E., Pughiuc, D., Richardson, S.D., Schwarz-schulz, B., Shah, A., Theobald, N., Gunten, U. Von, Wieck, S., Höfer, T., 2014. Chemosphere Emerging risks from ballast water treatment : The run-up to the International Ballast Water Management Convention. *Chemosphere* 112, 256–266.

doi:10.1016/j.chemosphere.2014.03.135

- Williams, S.L., Grosholz, E.D., 2008. The Invasive Species Challenge in Estuarine and Coastal Environments : Marrying Management and Science 3–20. doi:10.1007/s12237-007-9031-6
- Wu, D., You, H., Du, J., Chen, C., Jin, D., 2011. Effects of UV/Ag-TiO₂/O₃ advanced oxidation on unicellular green alga *Dunaliella salina*: implications for removal of invasive species from ballast water. *J. Environ. Sci.* 23, 513–519.
- Yao, K.S., Wang, D.Y., Ho, W.Y., Yan, J.J., Tzeng, K.C., 2007. Photocatalytic bactericidal effect of TiO₂ thin film on plant pathogens. *Surf. Coatings Technol.* 201, 6886–6888. doi:10.1016/j.surfcoat.2006.09.068
- Yazdanparast, F., Nouri, A., Rabbani, M., 2004. Identification and determination of PAHs compounds in Anzali International Wetland. *Int. J. Environ. Sci. Technol.* 1, 215–220.
- Yellow Spring Instrument Company, Y., n.d. YSI model 33 S-C-T meter [WWW Document]. URL https://www.ysi.com/File_Library/Documents/Manuals_for_Discontinued_Products/33-S-C-T-Meter.pdf
- Yellow Spring Instrument Company, Y., n.d. Instruction manual YSI model 57 [WWW Document]. URL https://www.ysi.com/File_Library/Documents/Manuals_for_Discontinued_Products/57-Dissolved-Oxygen-Meter.pdf
- Zhang, Z., Bai, M.D., Yang, B., Mindi, B., Xiyao, B., 2005. Treatment of Invasive Marine Species on Board by Using Micro-gap Discharge Plasma *. *Plasma Sci. Technol.* 7, 3025–3029.

Fig. 1:

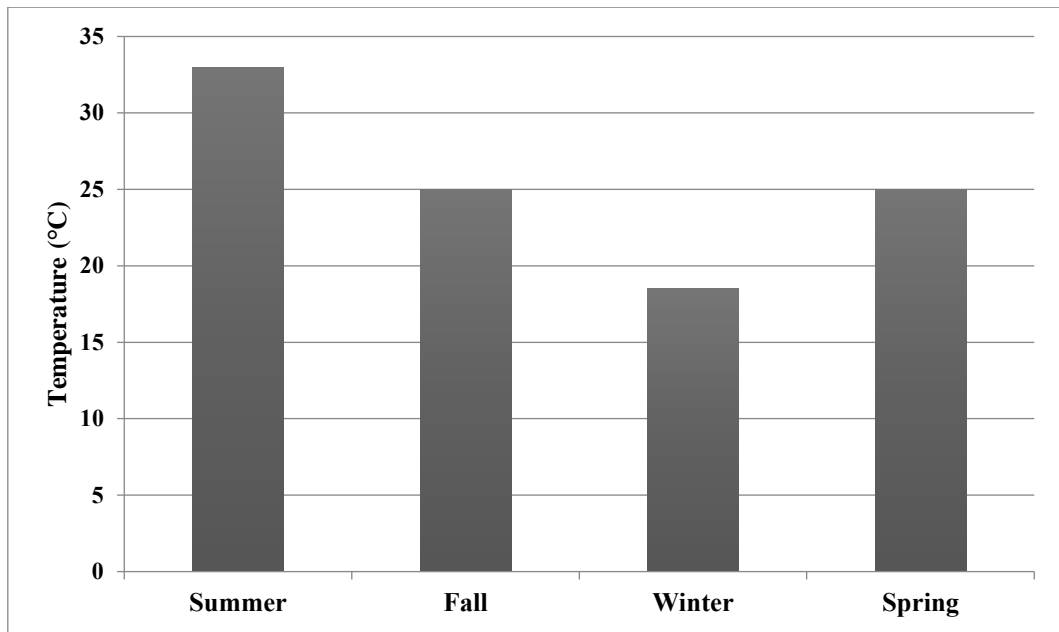


Fig. 2:

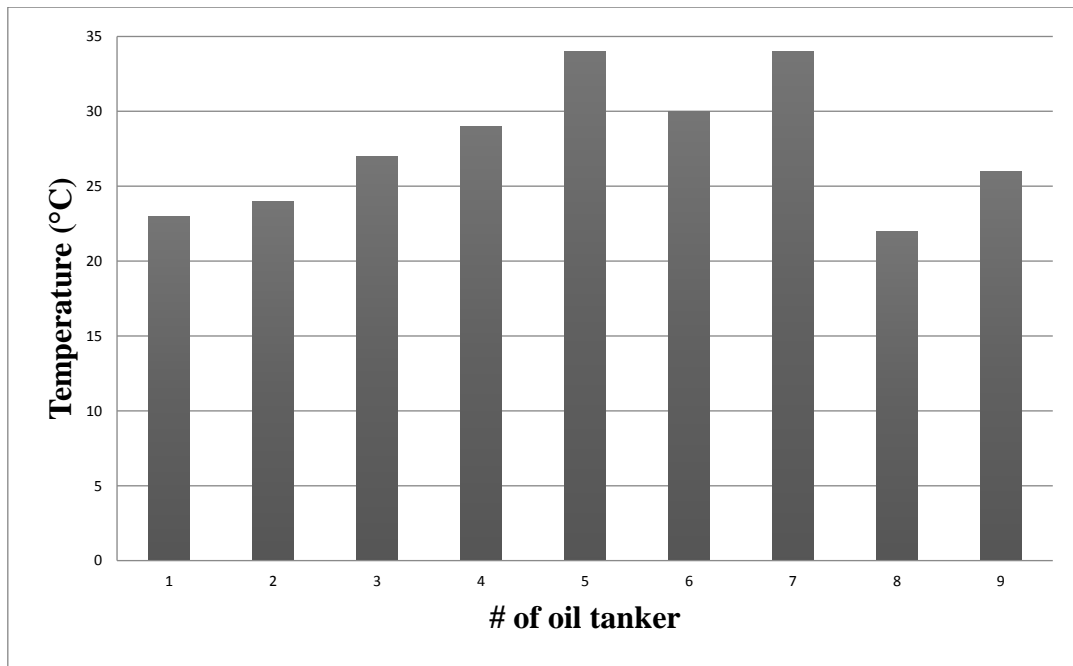


Fig. 3:

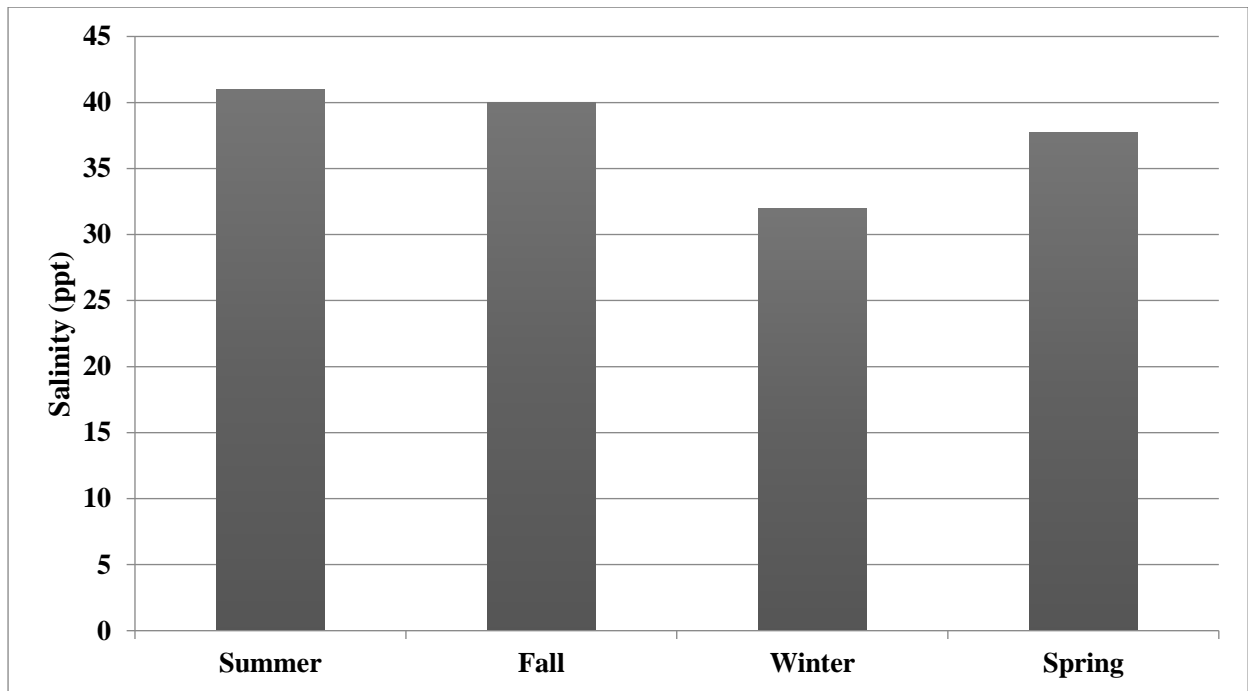


Fig. 4:

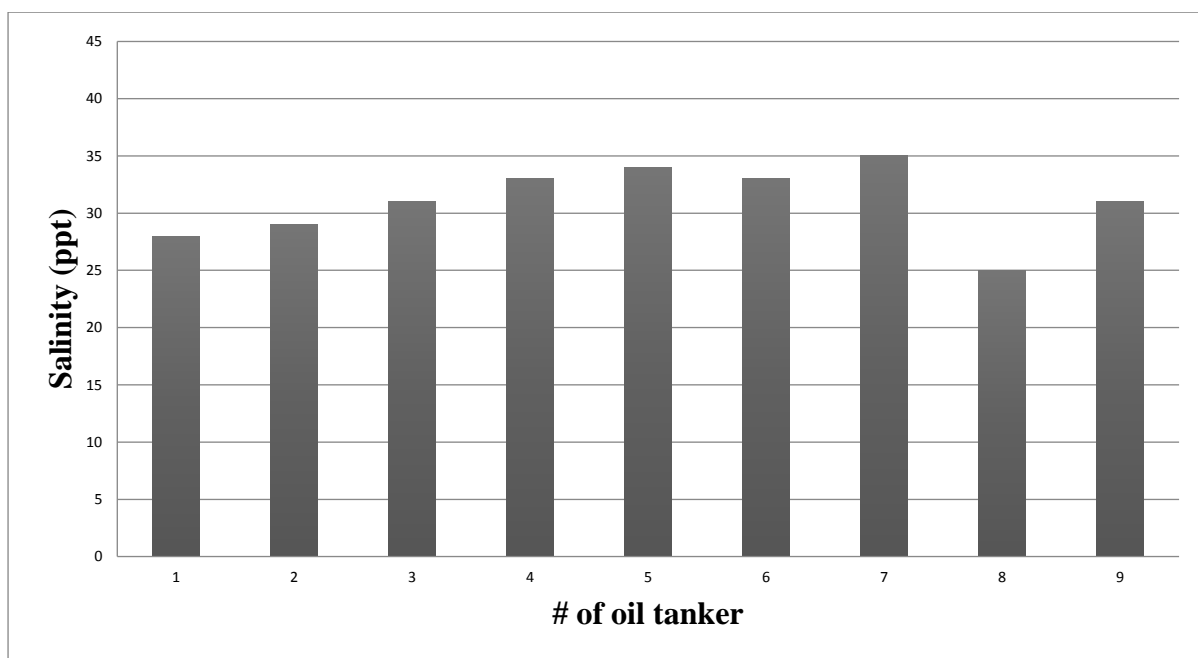


Fig. 5:

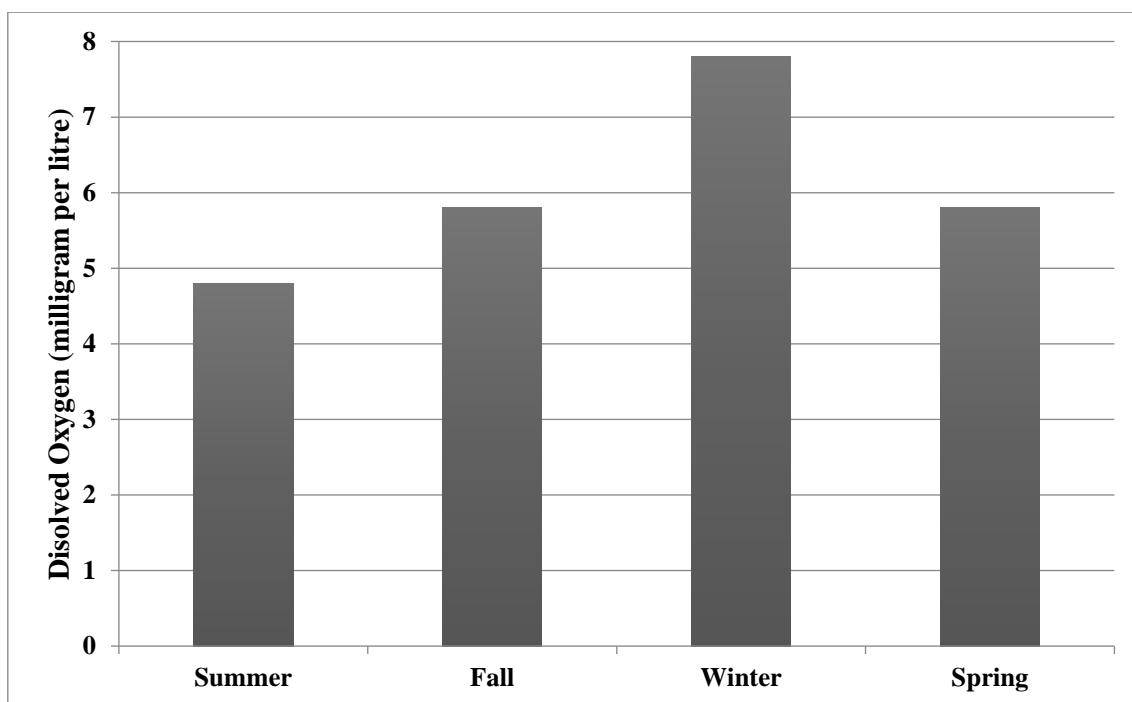


Fig. 6:

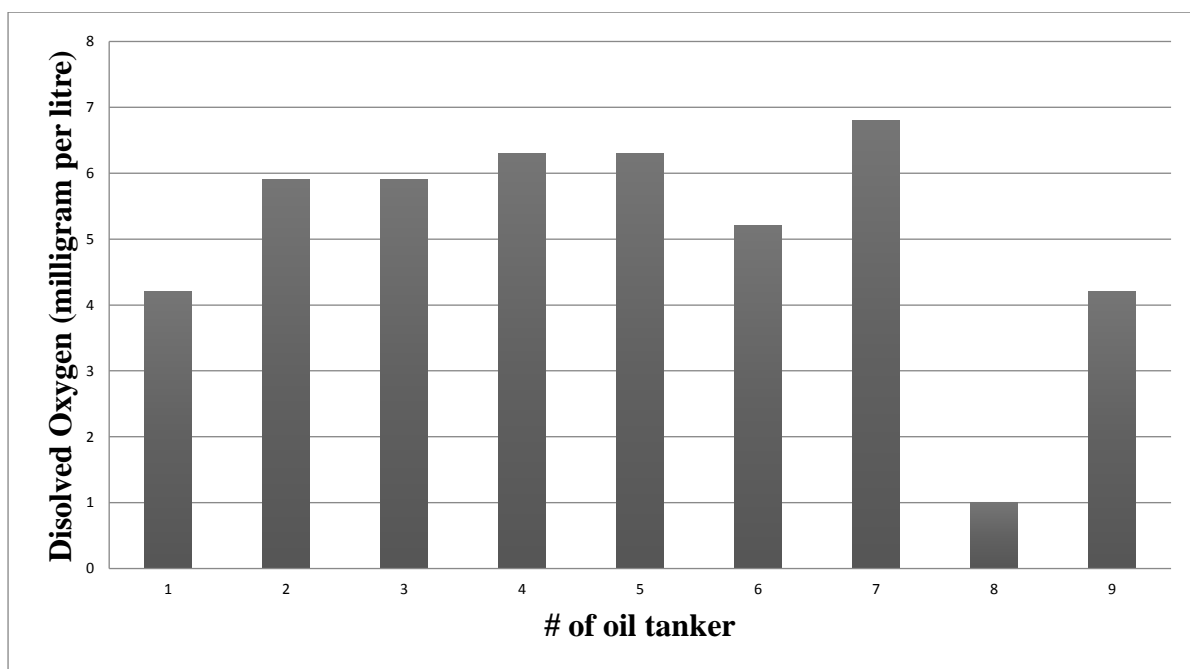


Fig. 7:

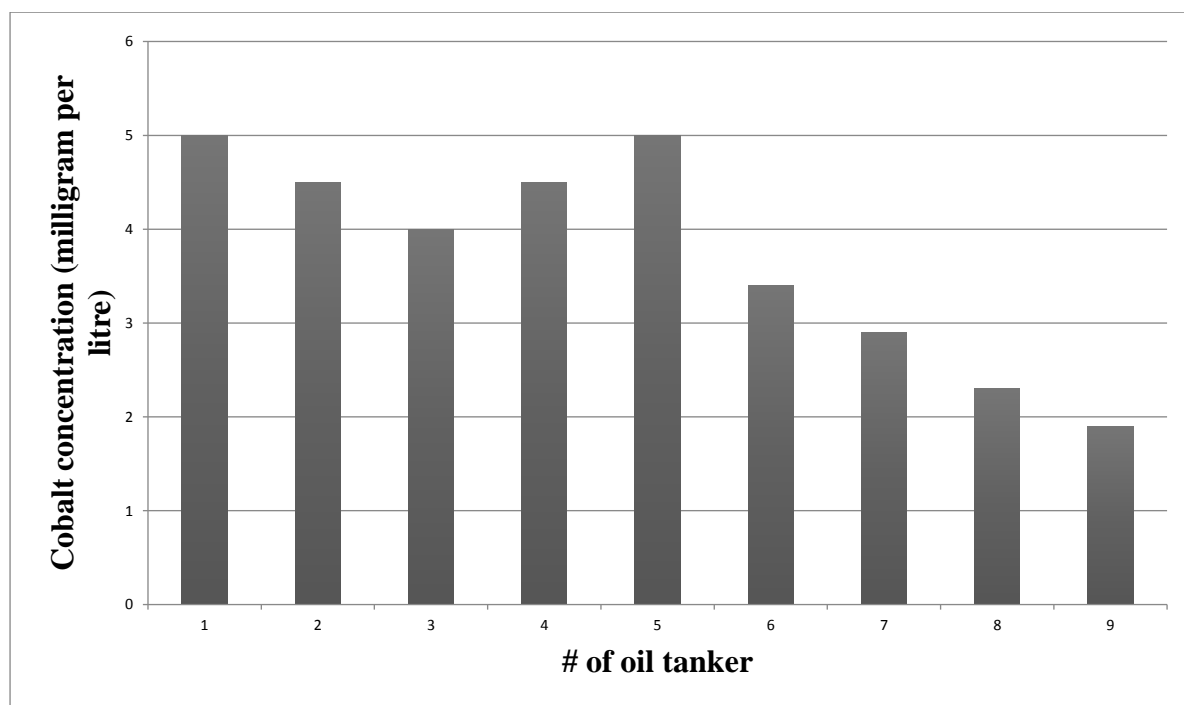


Fig. 8:

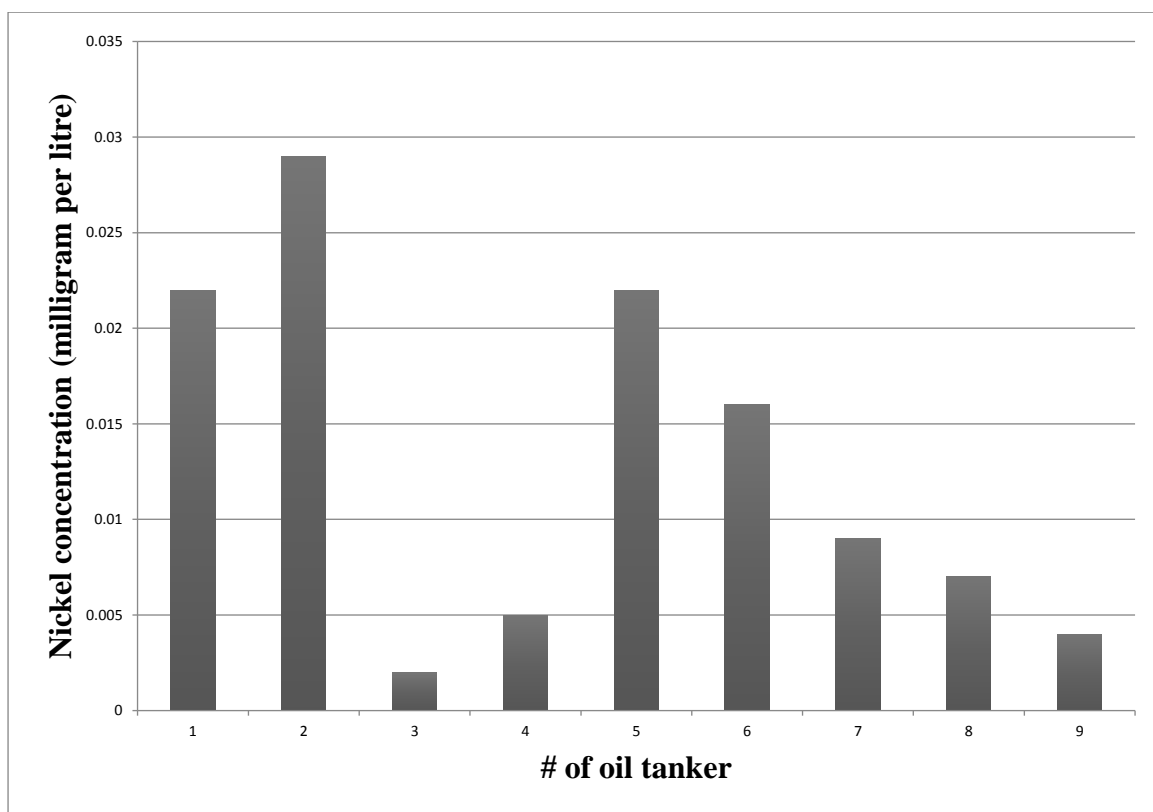


Fig. 9:

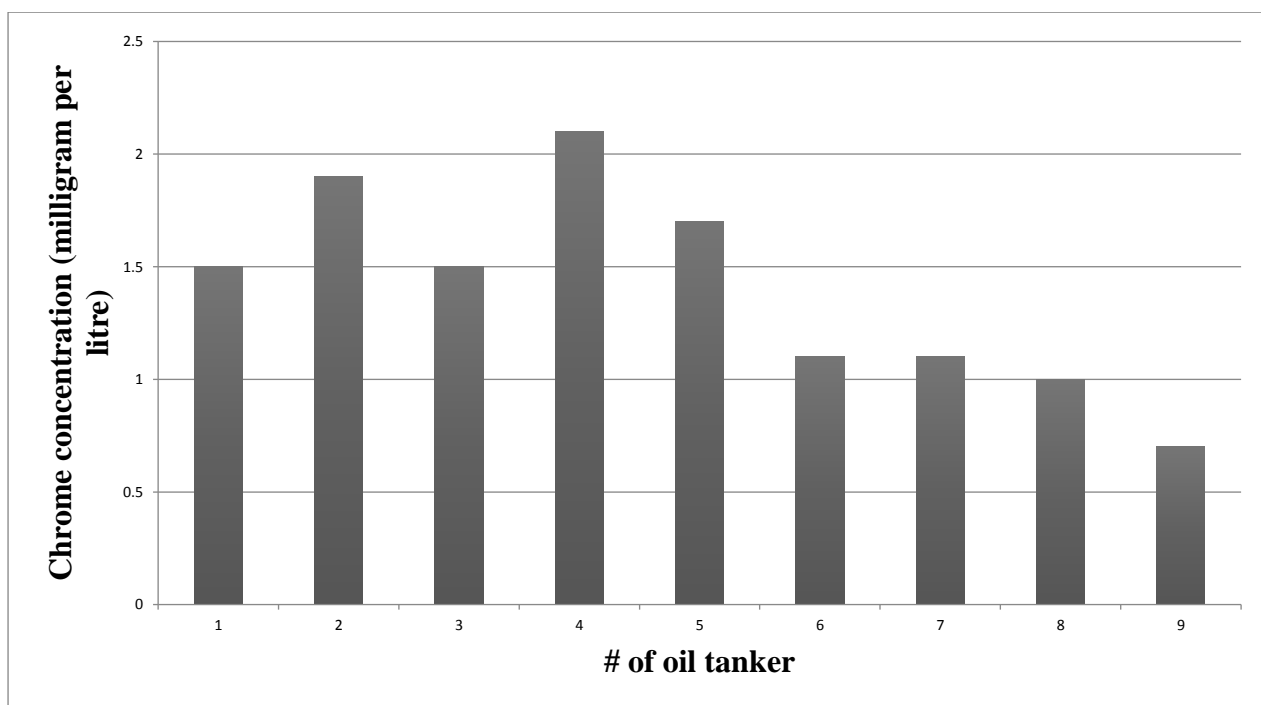


Fig. 10:

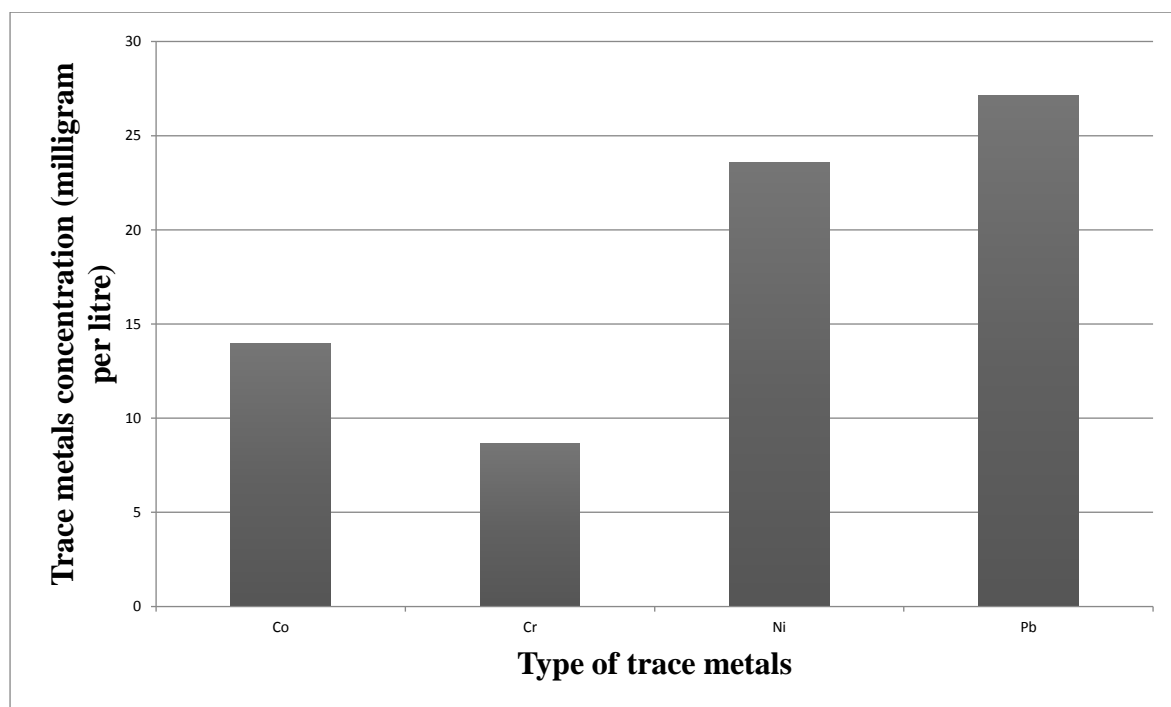


Fig. 11:

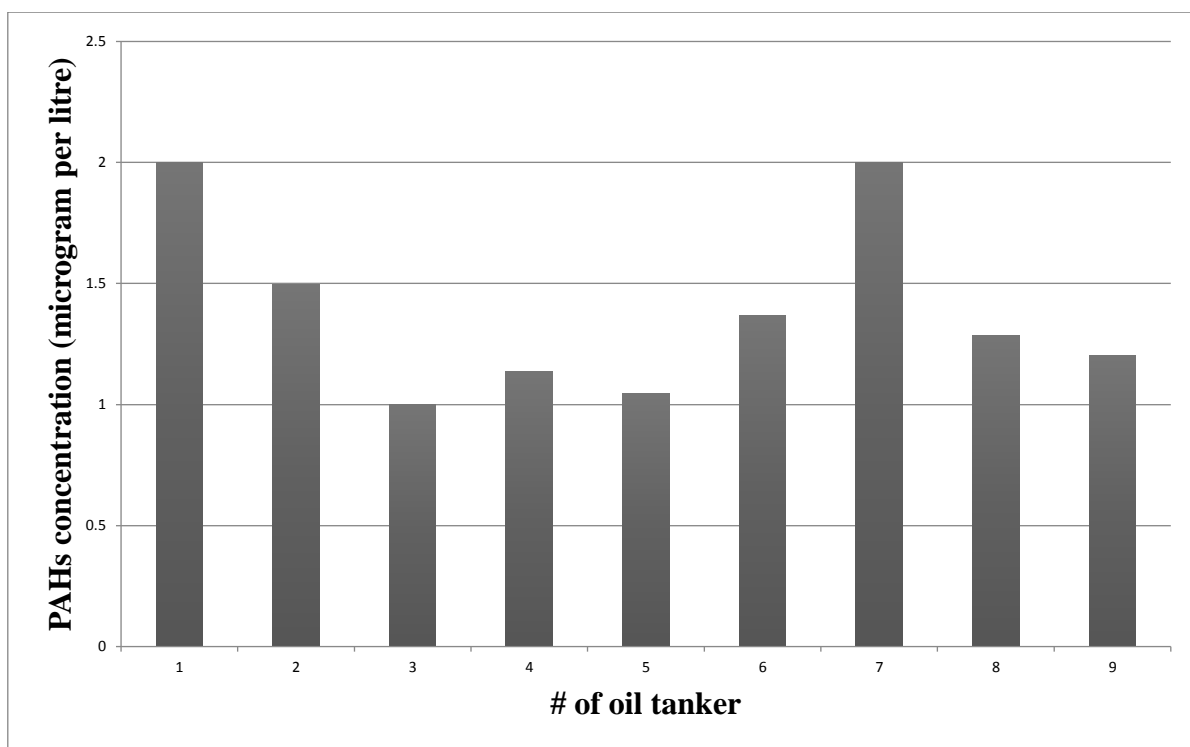


Fig. 12:

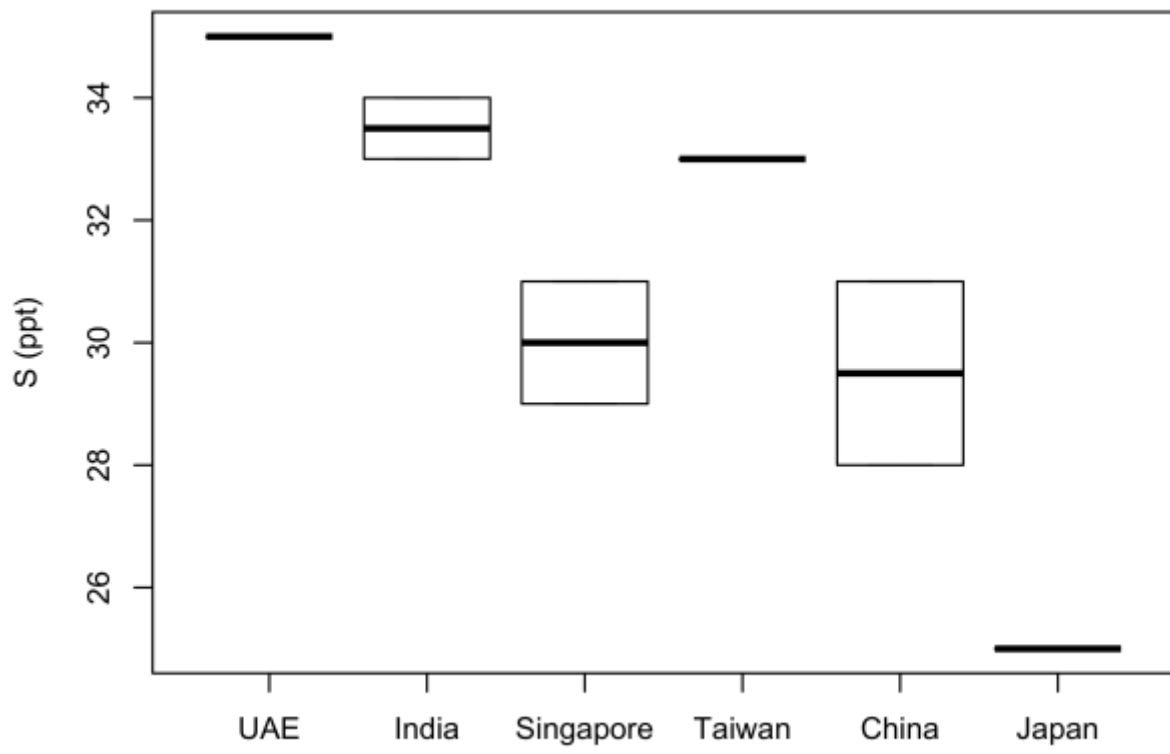


Fig. 13:

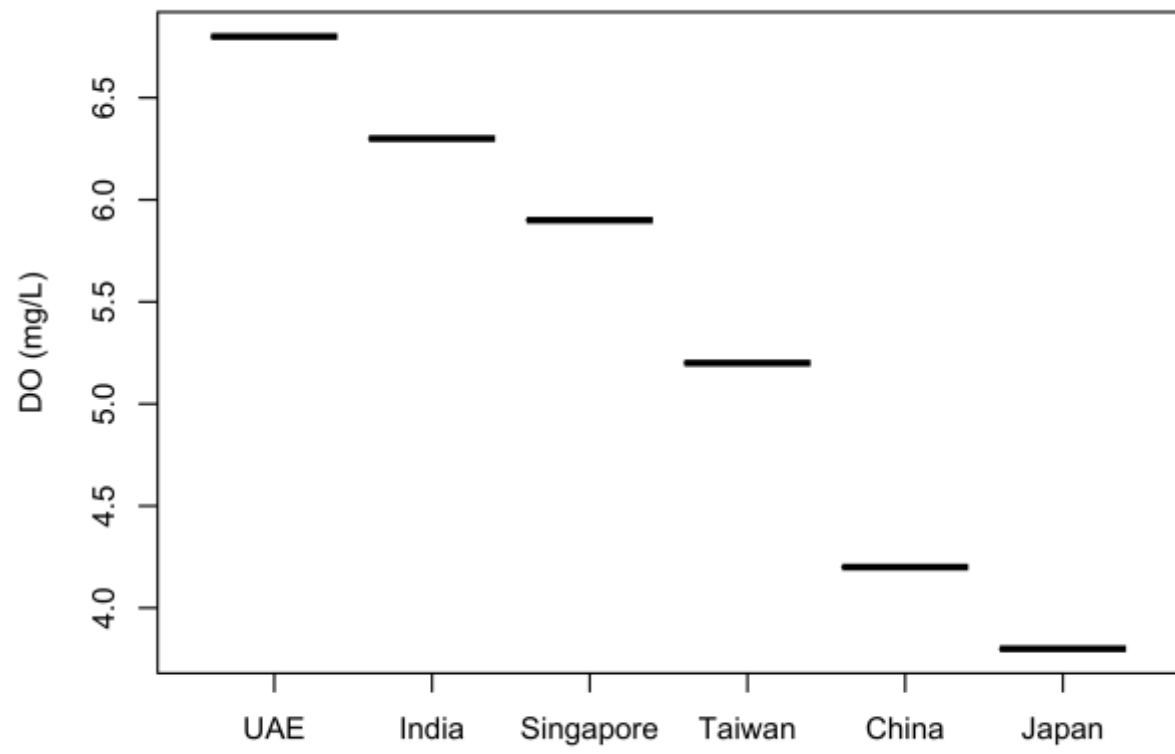


Fig. 14:

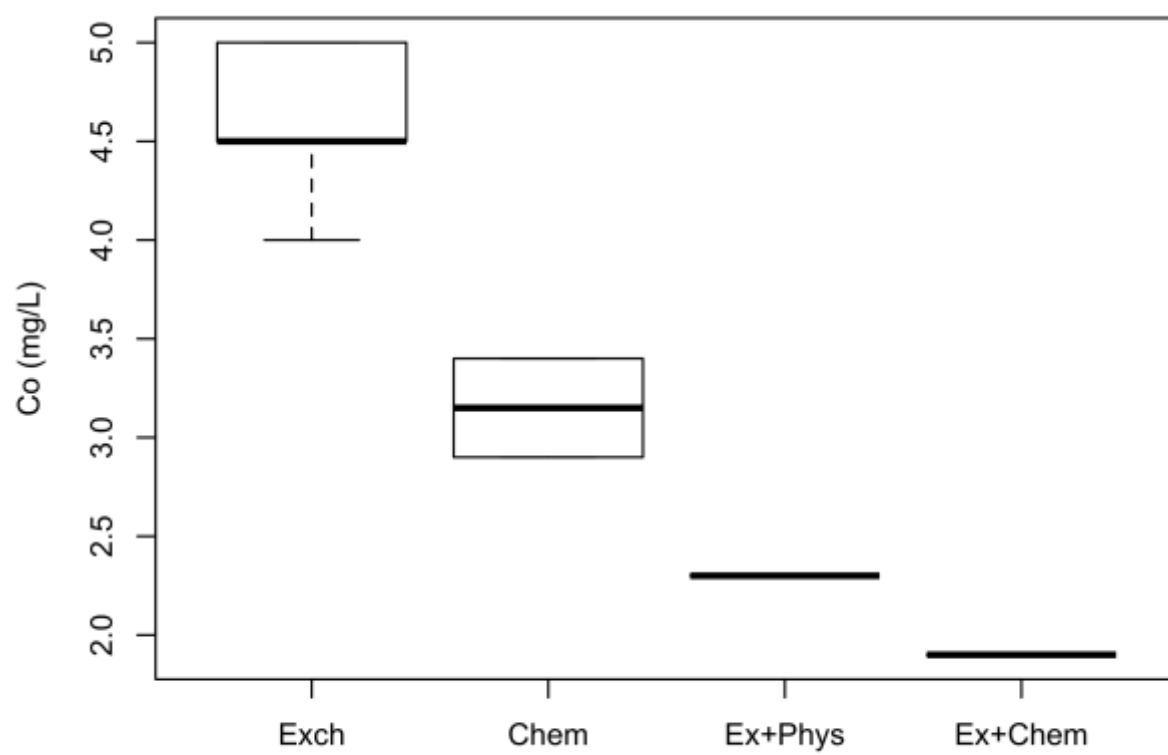


Table 1:

No.	Volume (m ³) of every oil tanker	Number of specified Oil Tanker	Volume (m ³) of oil tankers	Country of origin of oil Tanker
1	3,047,593	103	313,902,079	Iran
2	2,241,586	41	91,905,026	India
3	2,446,496	34	83,180,864	Saudi Arabia
4	319,300	96	30,652,800	UAE
5	1,358,786	20	27,175,720	Kuwait
6	939,188	23	21,601,324	Taiwan
7	848,612	19	16,123,628	Singapore
8	738,220	16	11,811,520	China
9	292,689	27	7,902,603	Japan
10	637,251	10	6,372,510	Egypt
11	266,056	9	2,394,504	South Korea
12	182,525	13	2,372,825	Qatar
13	83,564	9	752,076	Pakistan
14	128,005	4	512,020	Indonesia
15	96,373	3	289,119	Seri lanka
16	79,274	3	237,822	Greek
17	47,985	2	95,970	Spain
18	84,460	1	84,460	South Africa
19	52,798	1	52,798	Malaysia
20	47,990	1	47,990	Netherland
21	46,346	1	46,346	Australia
22	36,953	1	36,953	Yemen
23	33,700	1	33,700	Bahrain
24	33,229	1	33,229	Belgium
25	7,868	1	7,868	Oman
		440	617,625,754	

Table 2:

No.	Country	Total BW Capacity (tons)	BW On Board (tons)	BW Discharge (tons)	Type Of Ballast Water Management	Season of taking sample
1	China	101,493	88,146	88,146	Exchange	Spring
2	Singapore	105,306	85,617	85,617	Exchange	Spring
3	Singapore	57,457	51,930	50,664	Exchange	Spring
4	India	52,708	49,900	47,854	Exchange	Summer
5	India	96,882	76,311	75,306	Exchange	Summer
6	UAE	106,171	95,830	88,946	Chemical Treatment	Summer
7	Taiwan	103,539	75,306	50,270	Chemical Treatment	Summer
8	Japan	103,929	88,840	45,480	Exchange and Physical Treatment	Spring
9	China	107,057	93,910	68,099	Exchange and Chemical Treatment	Spring

Table 3:

No	Parameters	Method	Equipment	Reference
1	Temperature, Salinity	St.Method 2520	S.T.C. meter YSI model 33	(Yellow Spring Instrument Company, n.d.)
2	Dissolved oxygen	ASTM D888	D.O. meter YSI model 57	(Yellow Spring Instrument Company, n.d.)
3	PAHs	ASTM D4465 ASTM D5368	Spectrometer Perkin Elmer LS-5	(Yazdanparast et al., 2004)
4	Heavy metals	St.Method 111B,C	Atomic Absorption Spectrophotometer Perkin Elmer Zeeman 5100-PC	(Suna et al., 2000)